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Ownership unbundling and investment in electricity markets — A cross country study

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ABSTRACT

This paper is the first to explicitly test for the presence of a trade-off between static and dynamic efficiency and a trade-off between vertical economies and competition in a regulated industry, the electricity industry. We show for 16 European countries over the period 1998–2008 that higher electricity end-user prices in a country subsequently lead to larger aggregate investments in the capital stock, i.e. in generation, distribution and transmission assets. Moreover, there is a trade-off between vertical economies and competition. Ownership unbundling and forced access to the incumbent transmission grid increases competition but come at the cost of lost vertical economies. Generally, we find that regulation that affects only the *market directly*, like the establishment of a wholesale market or free choice of suppliers, increases aggregate investment. Regulation, however, that adversely affects the *incumbent directly*, like ownership unbundling, decreases aggregate investment spending.

1. Introduction

The Energy Sector Inquiry, COM (2006) 851 final, published on January 2007 highlighted a lack of competition in European energy markets, and although legal and functional unbundling were accepted in their positive impact, the European Commission concluded that these regulatory reforms are not sufficient to contribute to certain energy political goals. Further steps of unbundling such as ownership unbundling, an independent system operator (ISO) or an independent transmission operator (ITO) are seen as appropriate to stimulate competition, trigger investments, and accelerate the evolution towards an integrated European energy market.[4] Hence, the European Commission passed a third legislative package in September 2007. In its center lies the continuing vertical unbundling of transmission companies and long-distance transport in the electricity as well as the gas sector. However, up to now, no unambiguous evidence of positive effects of unbundling on consumers' welfare or prices exists, as mentioned in for example Fiorio and Florio (2009) and Florio (2007), nor is there evidence on its effects on investment incentives in energy markets, besides Nardi (2010).

Theory not only indicates that the unambiguously positive view of ownership unbundling by the European Commission is not warranted, there are much wider, inherent trade-offs between static and dynamic efficiency, and between vertical synergies and competition. Higher mark-up industries are likely to attract more new investments than low mark-up industries, provided there is a sufficiently high level of competition. Thus, higher prices – while inducing allocative and static inefficiencies – increase the attractiveness to invest and therefore dynamic efficiency.[5] Likewise, there is a well established literature on the benefits of vertical integration, ranging from the avoidance of double marginalization to the internalization of spillovers and better coordination, to name a few.

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[4] Ownership unbundling is the strongest form of unbundling. It requires that ownership and control of the transmission grid have to be fully separated from generation and distribution. For a detailed description of the less stringent ISO and ITO options, we refer to Balmert and Brunekreeft (2010).

[5] This is a variation of the trade-offs analyzed in the patent literature, see e.g. Nordhaus (1969).

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Forced access or break up of companies – while guaranteeing equal treatment of firms – are not for free and come at the costs of coordination failures and other diseconomies of vertical disintegration.[6]

This paper tries to fill this void of evidence on the effects of regulation on investment. Hence, we are the first to explicitly test for the effects of *ownership* unbundling of the transmission grid as well as final consumer *prices* on investments, and to corroborate the inherent trade-offs present in large sunk-cost network industries. We estimate dynamic panel regression models for the electricity industry in 16 European countries over the period 1998–2008, and find that ownership unbundling significantly reduces aggregate investment in the electricity industry. We also estimate an investment reducing effect of third party access to the electricity transmission grid. Moreover, there is a general trade-off between static and dynamic efficiency. Higher electricity end-user prices induce larger aggregate investments in the sector. Furthermore, we find that introducing competition via *market* based measures – such as establishing a wholesale market for electricity or abolishing minimum consumption thresholds for switching to alternative suppliers – *increases* investment spending. These measures increase competition *and* investment, since presumably they do not destroy the incentives of the incumbent to invest.

Under a cost-based regulation regime, as in electricity still in place in some countries, one may observe the well known Averch–Johnson effect, i.e. overcapitalization and a distorted (too high) capital–labor ratio, see Averch and Johnson (1962). Under these "gold plating" conditions, higher investments would not necessarily lead to higher welfare, since the level of investment could be too high from a social welfare point of view. However, in recent years most European countries have switched to incentive-based forms of regulation, as for example price-cap, revenue-cap or yardstick-regulation that do not suffer from overcapitalization. Furthermore, there are a number of reasons why investment requirements will be growing in the coming years, such that greater amounts of investments should lead to higher welfare. First, energy demand in Europe is rising continuously with the necessity of high future expansion investments. Second, due to ecological reasons as e.g. the goal to reduce global emissions, there is the need to accommodate increasing amounts of renewables which are "greener" but still more expensive than conventional generation assets. Third, many existing assets are very close to the end of their life span and therefore tremendous amounts of replacement investments are necessary. In accordance with Guthrie (2006), who states that delayed investments can be very costly from a welfare economic perspective, we therefore assume that higher investments in the electricity sector are desirable from a welfare perspective.

Methodologically, we care mostly about two problems. First, there are inherent endogeneity problems of investment determinants. "Regulation" may well be determined by investments, the same may be true for "prices". Therefore, we start our analysis by explicitly testing for Granger causal relationships among the main variables of interest. Based on this, we estimate instrumented regressions, applying consistent estimation techniques such as GMM and relying on both, external as well as internal instruments. Second, a general problem is that it is hardly possible to disentangle the effects of the coincident timing of different types of regulation. In this context, Pollitt (2008) e.g. points out: "…ownership unbundling of transmission networks may occur at the same time as privatization, the restructuring of generation or production markets, the introduction of incentive regulation etc." We try to disentangle these potentially coincident relations by utilizing the time series variation of the main variables of interest in our panel, and lagging them up to two years in our regressions.

The remainder of this paper is organized as follows. Section 2 gives a short literature overview over the existing theoretical models and empirical evidence on unbundling. Section 3 develops our main hypotheses. Section 4 describes the data set, Section 5 shows our econometric model specification, and Section 6 presents the main results as well as the robustness checks. Finally, Section 7 concludes.

2. Literature survey

Several theoretical articles analyze the impact of ownership unbundling on consumer prices and investments. Bolle and Breitmoser (2006) show that ownership unbundling leads to a more effective regulation. They, however, highlight that it causes the problem of double marginalization, which implies price increases in the long run. Overall, they find that the negative effects of double marginalization outweigh the positive effects in such a way that legal unbundling becomes preferred to ownership unbundling. Cremer et al. (2006) also show that ownership unbundling is more detrimental to social welfare than legal unbundling. They ascribe this effect to the higher incentives for investments under legal unbundling, since under this regime other parts of the company can still benefit from investments made by the formerly vertically integrated company, which is not the case under ownership unbundling. In a similar approach, Höffler and Kranz (2011) confirm the previous findings and show that the desirable properties of legal unbundling with special regard to social welfare and investment incentives can only be achieved if there is a strong, effective and independent regulation. For a comprehensive survey on the effects of unbundling in the electricity sector, see Meyer (2012). He concludes that there are significant vertical synergies that are lost particularly if generation unbundling is introduced (separation of generation from the two network stages transmission and distribution). According to Meyer (2012), the ISO option, where ownership remains unchanged, while operating and investment decisions are handed over to a company without commercial supply interests, would be the "golden mean".

In contrast, Pollitt (2008) criticizes Bolle and Breitmoser (2006) and Cremer et al. (2006) for their underlying assumptions. He reports that opposing results can be expected if more realistic assumptions are incorporated. For the former study he states that their model should take into account anti-competitive information advantages of legal unbundling for the rest of the integrated firm, while the latter does not consider the competition enhancing effect of ownership unbundling as well as the fact that double marginalization assumes one-part tariffs, which is usually not the case for the electricity sector. Brunekreeft (2008) and Brunekreeft and Meyer (2008) analyze the possible effects of different types of unbundling in electricity markets on competition and cost evolution by means of a cost–benefit analysis. They deduce that ownership unbundling may not directly lead to expansion investments, but if capacity becomes scarce, it may support investment decisions if the considered time period covers about 20 years.

Up to now no unambiguous empirical evidence of positive effects of ownership unbundling on prices or market concentration exists, nor is there any econometric evidence on its effects on investment incentives in energy markets. Nevertheless, several studies cover the impact of different types of regulation or liberalization. Steiner (2001) is one of the first articles to deal with the effects of liberalization on consumer prices. For her analysis she takes data from 19 OECD countries spanning a time period from 1986 to 1996. She finds that unbundling of generation and transmission facilities leads to increasing efficiency for the overall sector, however, the possible benefits are not necessarily passed on to private consumers via lower prices. However, no distinction between legal and ownership unbundling is made.

Hattori and Tsutsui (2004) unlike Steiner (2001), find that unbundling appears to increase prices. Again, no explicit distinction of the different types of unbundling is made. Copenhagen Economics

[6] There are various studies on economies of vertical integration in the electricity sector. In a recent paper Arocena et al. (2009) analyze 116 US firms for the year 2001. They find vertical scope economies of 8.1% at the mean, horizontal scope economies of 5.4% and overall scope economies of 13.5%. Previous research as e.g. Kwoka (2002) or Kaserman and Mayo (1991) draw a similar picture. Empirical evidence is not only restricted to the US. Arocena (2008) analyzes 12 Spanish utilities for the period 1989–1997 and reports cost and quality gains from vertical integration (in the range of 1.1% to 4.9%) and horizontal integration (in the range of 1.3% to 4.3%).

(2005) examines the level of market opening in several network industries by means of a dynamic panel data model. The study focuses on the EU-15 countries from 1993 to 2003 and concludes that higher levels of unbundling (with ownership unbundling as the highest form) lead to price reductions and increasing efficiency. Moreover, they conclude that unbundling of the transmission grid is the most important element of market opening. However, for the gas sector they cannot confirm this negative effect of unbundling on prices.

More recently, Fiorio and Florio (2009) show for the electricity industry that vertical integration leads to higher final consumer prices, and using a standard probit model, they conclude that consumers are less satisfied if firms are integrated. In line with earlier studies, their results for the gas industry differ substantially. Herein, prices and vertical integration are uncorrelated, and consumers are more satisfied with higher levels of integration. Similar studies dealing exclusively with the gas industry are Brau et al. (2010) and Growitsch and Stronzik (2009). The latter paper explicitly accounts for ownership unbundling, but the authors do not find a significant effect of ownership unbundling on prices.

Most of the previously mentioned articles focus on the impact of unbundling on prices or efficiency, but neglect the effects on investments. The most important empirical study in this context is by Alesina et al. (2005), who analyze different regulatory reform processes in seven network industries in 21 OECD countries covering the time period 1975 to 1998. The authors show that regulatory reform of product markets has a positive effect on investments. Analyzing the gas and electricity sector jointly, they come to the conclusion that investments increase with higher levels of unbundling. However, they do not differentiate between ownership and legal unbundling.

Nardi (2010) undermines these findings. He analyzes the impact of ownership unbundling on grid investments and quality. Although he finds higher grid investments in the network, he further shows that a substantial lack of quality emerges that confirms the resulting diseconomies of coordination when separating ownership and control of different company parts. According to the author his results should be seen as first findings, since only qualitative investment data is available and therefore no multivariate regression analysis can take place. Nevertheless, to our knowledge this is the only paper that explicitly analyzes the impact of ownership unbundling on (grid) investments, in spite of the difficult data situation.

Summarizing, there is a lack of robust evidence on the effects of prices on investment as well as on the effects of ownership unbundling and other forms of access regulation on investment. We next turn to our hypotheses regarding the determinants of investment.

3. Hypotheses on the determinants of investments

There is a general ambiguity of the effects of competition and regulation on investment. In what follows, we detail the likely effects of three categories of investment determinants, (1) “prices”, (2) “regulation”, and (3) ownership structure.

3.1. The effects of prices on investments

Ceteris paribus, a higher price should lead to larger investments, since rents are higher from expanding the capital stock in a high mark-up industry than in a low mark-up industry. This effect can be called “Schumpeterian”, and it is the underlying force in Dixit and Stiglitz (1977) type of competition and investment/innovation models. Thus, a positive coefficient on prices in an investment model proxies for the *trade-off between static and dynamic efficiency*.[7]

However, there are at least three objections to this “naive” line of reasoning. First, only if there is a reasonably high threat that the counterfactual of not investing is that another firm will invest and capture the accruing rents, the Aghion et al. (2005) “escape competition” effect should lead to a positive relation between investments and mark-ups. Larger mark-ups then imply higher opportunity costs of not investing if there is competition for these rents. Thus, higher prices will induce higher investment only when there is a reasonably high threat to lose these rents if not investing.

Second, a larger mark-up does not need to only capture the efficiency of the firm and thus its investment opportunities, it could also capture its monopoly rents. If so, the effects of larger prices on investment incentives depend in an intricate way on the threat of losing these rents, i.e. on the firm relevant counterfactual of not investing. When there is no danger of losing existing rents, so that the firm is essentially an uncontested monopoly, the counterfactual of not investing is the status quo, i.e. no other firm can compete existing rents away. This gives rise to the Arrow (1962) “replacement effect”, implying a low propensity to invest in new products or processes. Larger prices then are just an indication of a low threat of entry, and the quasi monopoly invests very little, since new profits from investments just replace old profits.

Third, high prices and investments may be endogenous. Investment, or more precisely the future depreciation of it, increases regulated energy prices by definition if regulation is “cost-plus”. We econometrically tackle these problems of causality below.

3.2. The effects of regulation on investments

Due to the long investment horizons and cost irreversibility in the electricity industry, changes in regulation are one of the most important determinants of firm investment behavior. Logically, regulation can be differentiated into (1) regulation affecting only the *market* directly (e.g. the existence respectively non-existence of a liberalized wholesale market or of a minimum consumption threshold of consumers switching supplier) and (2) regulation affecting also the *incumbent* directly (e.g. legal/ownership unbundling or third party access). While in the latter case regulation affects vertical coordination synergies, in the former case regulation does not affect the internalization of investment spillovers.

3.2.1. Regulation affecting the incumbent directly

Regulation and in particular access regulation should increase the ease with which firms can enter the market and compete with the incumbent. However, the effects of regulation on investments are ex ante ambiguous and may differ between incumbents and entrants. Stricter (access) regulation and in particular ownership unbundling of the activities of the incumbent on different stages of the production process can have detrimental effects.

First, double marginalization problems may be introduced by ownership unbundling, which decrease the overall rents that can be earned in this market and therefore investments. The double marginalization problem, however, suffers from three flaws to be a main explanation of effects. First, it depends on linear pricing; with non-linear pricing (e.g. two-part tariffs) the effect may vanish. Second, it depends on market power downstream, which may not be present. Third, and in our context the most important point, electricity networks are regulated, and if regulators achieve cost-based regulatory access charges, the double marginalization problem disappears. In our case, therefore, other explanations than the double marginalization problem may be responsible, if we find negative effects of access regulation and ownership unbundling on investment.

Such explanations, secondly, may be spillovers and network externalities between up- and downstream operations that can no longer be internalized by the same firm.[8] For this argument to be a convincing explanation one has to argue that the electricity sector differs from other sectors of the economy, since most of the transactions in an

[7] The interrelation between static and dynamic efficiency in the context of regulation is extensively described in Guthrie (2006).

[8] Buehler et al. (2004) call this the *vertical externality argument*. In their model a separated upstream monopolist ignores the positive effect of investment on downstream profits, and therefore his incentives to invest are smaller than under vertical integration.

economy are made by decentralized agents, and we would hardly think that the outcome is inefficient overall. So is the electricity sector different? We argue that it is. While vertical synergies are also present in other sectors of the economy, non-regulated sectors have the option to solve the problem of internalization by optimal contracting, not constrained by regulatory restrictions.[9] One such solution *is* vertical integration,[10] others include joint ventures, revenue or cost sharing contracts, or optimal pricing. Thus, the *combination* of strict network regulation, i.e. restrictions on decentralized solutions to the internalization problem like cost- and revenue-sharing, and ownership unbundling may reduce investment incentives.

Thirdly, electricity may be characterized by a particularly large necessity of coordination, not least by the fact that demand has to be equal supply at each point in time. Thus, a coordination failure between infrastructure investments and generation assets may result if the decision making entities differ. However, while one may argue that coordination failure leads to less investment in complementary assets, the effect of a coordination failure in the regulated electricity sector is less obvious. In particular, coordination failure may even result in *more* rather than less investment, if oversized networks are maintained to achieve stability of the network. Moreover, in most countries transmission operators are required by law to connect even decentralized generators, thus solving – albeit in a costly way – the coordination failure problem.

Finally, a separated grid operator is a much smaller firm than the vertically integrated incumbent, and due to size and financial resources effects may invest less. This argument, however, rests on the assumptions of imperfect capital markets, i.e. asymmetric information and/or transaction costs.[11] Moreover, for the highly inelastic parts of the regulated electricity sector, regulators can counteract this problem by setting appropriate allowed rates of return.

Summarizing, if we empirically obtain a negative effect of access regulation or ownership unbundling on investment, the most likely explanation appear to be vertical externalities and possibly coordination failure. The *combination* of strict network regulation, i.e. restrictions on decentralized solutions to the internalization problem like cost- and revenue-sharing, and ownership unbundling may reduce investment incentives.

The potential positive effects of (access) regulation and in particular ownership unbundling are related to increased competition in the market and thus investments. In case of ownership unbundling, it reduces the scope for discrimination against entrants, since the newly created grid operator has an incentive to spur competition upstream (i.e. generation) and downstream (i.e. retail) and treat all firms equally. This increases investments by entrants, but could also increase investments by incumbents depending on where on the inverted U-shape the industry is positioned. Moreover, Foros (2004) and Kotakorpi (2006) show that increased competition, if it increases variety and innovation and, concomitantly demand, might encourage investments by incumbents. An example for the electricity sector is the introduction of smart grids, where substantial investments have to be made in the coming years.

3.2.2. Regulation affecting only the market directly

Regulation that affects only the market (directly) is associated with the process of liberalization. Accordingly, the introduction of downstream competition between distributors/retailers via liberalization (e.g. through the foundation of a liberalized wholesale market or through a lower minimum consumption threshold of consumers switching their supplier) should reduce final consumer prices for a given grid tariff, see Buehler et al. (2006). Decreasing prices lead to a higher quantity of electricity sold, and both grid companies as well as generators should invest more, with the effects on downstream retailers being ambiguous.[12] Moreover, in contrast to regulation that adversely affects vertical coordination synergies, regulation that affects only the market directly does not affect the internalization of investment spillovers.

Summarizing, in general, the theoretical effects of regulation on investment are ambiguous and intricate, and it is an empirical question which effects dominate. However, one may hypothesize, that regulation that introduces competition without undermining the incentives of the incumbent to invest via preserving the internalization of investment spillovers is preferable from a dynamic efficiency perspective. In the empirical part of the paper we test for the net effects of access regulation and ownership unbundling on investment.

3.3. The effects of ownership structure on investments

The ownership structure of firms in the electricity sector may affect investments in two ways, first via efficiency and second via incentive or objective effects. Unambiguously, more efficient firms invest more, because they serve a larger market including also low-willingness-to-pay consumers (demand effect) and/or because they obtain a larger market share (competitive effect). Therefore, if public ownership implies X-inefficiency, we should see less investment in predominantly state-controlled energy sectors. On the other hand, the state and state-controlled firms may have objectives or incentives that differ from privately-controlled firms, and these objectives may include the build-up of a good and secure infrastructure for electricity. Thus, state-controlled firms may invest more than privately-controlled firms. We test empirically which effect dominates.

4. Data

Table 1 presents the definitions and sources of the variables used in the subsequent regression analysis. The main sources are Eurostat, IEA (International Energy Agency), EU documents, and the OECD. Our sample is an unbalanced panel which contains data for 16 European countries over the period 1998–2008. Investments, *I*, are gross investments in tangible goods in the overall electricity industry, and thus include investments in generation, distribution and transmission assets of the incumbents as well as of the entrants. We thus look at aggregate investment in the electricity industry. Capital stock data is not readily available, thus we use the perpetual inventory method, see e.g. Fazzari et al. (1987) and Salinger and Summers (1983). Capital stock, *K*, is calculated according to the formula: $K_t = K_{t-1} - \delta K_{t-1} + I_t$, where K_t is the capital stock in period *t*, δ is the depreciation rate and I_t equals investments. Due to the long-term nature of investments in the electricity sector we assume a depreciation rate of 5%, see e.g. Alesina et al. (2005). We exclude the first three years of every country panel to arrive at the first K_t used in the regressions.[13] The dependent variable is I/K.

The variables of main interest are final consumer prices,[14] *P*, the four regulatory variables, ownership unbundling, *OU*, third party access to

[9] Although such solutions may be constrained by general competition law.

[10] This is well recognized by competition authorities, since non-horizontal merger, i.e. vertical or conglomerate, merger guidelines are much more lenient than horizontal merger guidelines, on the grounds that efficiency effects are more likely in vertical mergers than in horizontal mergers (see e.g. http://europa.eu/rapid/press-release_IP-07-1780_en.htm?locale=en).

[11] See Myers and Majluf (1984) and Stiglitz and Weiss (1981) for theoretical explanations of cash constraints, see empirically the large literature that was sparked by Fazzari et al. (1987).

[12] Note the seemingly contrasting effects of "prices" on investment, when compared to their effects as described in Section 3.1. However, there is no contradiction here, since in Section 3.1 higher prices – ceteris paribus, i.e. at equal output – proxied for larger rents to be earned and thus the attractiveness to invest in that business. In the Buehler et al. (2006) argument, lower prices lead to larger output, i.e. due to accelerator effects investment is increased.

[13] We also tried four and five years, but since results are very similar we only report the results of leaving out the first three years of investment. This also holds true for the special case of Spain, where there was very little investments in the first three years (1995–97) of our sample, possibly due to the beginning regulatory reform process from 1997 onwards.

[14] For our purpose of testing for the effects of "prices" on aggregate investment, net final consumer (retail) prices are preferable to other prices like wholesale prices or grid access charges, since our focus is on the electricity sector as a whole and not on the different stages of the industry.

Table 1
Variable definitions.

Variable	Variable description	Source
Investments, *I*	Gross investments in tangible goods in the overall electricity industry of a country (i.e. investments in generation, distribution or transmission assets)	Eurostat
Capital stock, *K*	Since capital stock data is not directly available from the data base, we derive it indirectly from investments using the perpetual-inventory method	Own calculations
Final consumer prices, *P*	Electricity end-user prices for households in USD per kWh. Prices are purchasing power parity corrected and taxes are subtracted.	IEA/OECD
Ownership unbundling, *OU*[a]	Ownership unbundling of the transmission grid (0 = no OU, 1 = OU)	Based on EU publications + contact with regulatory authorities
Third party access, *TPA*	Third party access to the electricity transmission grid (0 = no TPA, 1 = negotiated TPA, 2 = regulated TPA)	OECD
Liberalized wholesale market, *LWM*	Existence of a liberalized wholesale market for electricity (0 = no LWM, 1 = LWM)	OECD
Minimum consumption threshold, *MCT*	Minimum consumption threshold for consumers to be allowed to choose their electricity supplier (0 = no choice, 1 = more than 1000 gigawatts (GW), 2 = between 500 and 1000 GW, 3 = between 250 and 500 GW, 4 = less than 250 GW, 5 = no MCT)	OECD
Public ownership, *PO*	Ownership structure of the largest companies in the generation, transmission, distribution and supply segments of the electricity industry (0 = private, 1 = mostly private, 2 = mixed, 3 = mostly public, 4 = public)	OECD
Per-capita consumption, *CON*	Per-capita consumption of electricity	OECD
Long-term interest rate, *R*	Long-term interest rate	OECD
Share of nuclear generation capacity, *NUC*	Country specific share in nuclear power generation capacity	OECD
Share of hydro generation capacity, *HYD*	Country specific share in hydro power generation capacity	OECD
Incentive regulation, *IR*	Introduction of incentive regulation in a country (0 = no incentive regulation, 1 = incentive regulation)	Based on other studies + contact with regulatory authorities
Government orientation (right–left-wing), *GOR*	Party orientation of the biggest governing party with respect to economic policy (1 = executive is right wing, 2 = center, 3 = leftwing)	Worldbank database on political institutions
Herfindahl Government Index, *HERFGOV*	The sum of the squared seat shares of all parties in the government	Worldbank database on political institutions
Government stability, *STAB*	Percent of veto players who drop from the government in any given year (*STAB* ranges from 0 (low stability) to 1 (high stability))	Worldbank database on political institutions

[a] In four countries of our sample there is more than one transmission system operator (TSO), in Austria we have three TSO's, in Germany four, in Italy nine and in Portugal three. For our sample period none of the TSO's in Austria and Germany is ownership unbundled. In Italy we only consider the biggest TSO (TERNA S.p.A.) with a market share of more than 90%, which is ownership unbundled since 2004, see Table 2b. In Portugal we only look at the TSO (now called REN — Redes Energéticas Nacionais, SGPS, S.A.), who is responsible for the mainland of Portugal.

the transmission grid, *TPA*, liberalized wholesale market, *LWM*, minimum consumption threshold, *MCT*, and the public ownership variable, *PO*. Electricity end-user prices for households are purchasing power parity and taxes corrected, and are measured in USD per kWh. The regulatory variables are coded so that larger values indicate more stringent regulation. Thus, we code *OU* as 1 if there is ownership unbundling of the transmission grid, and 0 if there is no *OU*. *OU* is based on several publications of the EU Commission, namely different benchmarking reports and various reports on progress in creating the internal gas and electricity market. In instance of any misleading or conflicting evidence, the corresponding national authority has been contacted. *TPA* is 2 if there is regulated third party access, 1 if third party access is negotiated, and 0 if there is no third party access. The existence or non-existence of a liberalized wholesale market for electricity is coded as 1 = *LWM*, and 0 = no *LWM*. If *MCT* = 5, there is no minimum consumption threshold for consumers to be allowed to choose their electricity supplier, and if *MCT* = 0 consumers have no choice of the supplier. *MCT* takes on values in between depending on the amount of electricity that must be consumed annually. Thus, *MCT* = 4 if there exists a threshold but this threshold is smaller than 250 gigawatts (GW), *MCT* = 3 if minimum consumption is between 250 and 500 GW, *MCT* = 2 if minimum consumption is between 500 and 1000 GW, and *MCT* = 1 if annual consumption must be more than 1000 GW. Finally, we measure the ownership structure of the largest companies in the generation, transmission, distribution and supply segments of the electricity industry by *PO*, which takes on the value 0 if firms are private, 1 if they are mostly private, 2 if they are mixed, 3 if they are mostly public, and 4 if they are public.

The following variables are used as external instruments in the underlying instrumented regressions. *HYD* and *NUC* represent the country specific shares in hydro or nuclear power generation capacity. *IR* is a dummy variable being equal to 1 in case incentive regulation has been introduced in the underlying country, otherwise it is 0. *GOR* stands for the party orientation of the biggest governing party with respect to economic policy. 1 equals a right wing executive, 2 a center executive and 3 a left wing executive. *HERFGOV* is the Herfindhal Government Index, measuring the sum of the squared seat shares of all parties in the government. *STAB* denotes the government stability. This variable counts the percent of veto players who drop from the government in any given year. It ranges from 0 (low stability) to 1 (high stability).

Tables 2a and 2b present evidence on investment-to-capital ratios, prices, on the regulatory variables and on ownership. Table 2a shows that average investment rates vary between 4% (Austria, Czech Republic, Germany, Slovak Republic) and 30% for Spain. The average *I*/*K* is 8.8%. Electricity is cheapest in Norway and Sweden (average of 5 USD cents per kWh net of taxes) and most expensive in Portugal (20 cents). The average kWh costs around 12.5 cents.

For our reporting period five countries (Austria, Belgium, France, Germany and Hungary) do not have ownership unbundling at all, although of course there is legal unbundling in all countries (see Table 2b). At the other extreme, Finland, Sweden and the UK were the first to ownership-unbundle the transmission grid from generation.

Table 2a
Descriptive statistics.

Country	I_t/K_{t-1} (1998–2008)			P_t (1998–2008)		
	Mean	Min	Max	Mean	Min	Max
AT	0.0425	0.0269	0.0624	0.1134	0.1000	0.1482
BE	0.0650	0.0574	0.0712	0.1353	0.1290	0.1564
CZ	0.0380	0.0283	0.0480	0.1386	0.0830	0.1906
DK	0.0611	0.0321	0.1261	0.0835	0.0600	0.1174
FIN	0.0437	0.0190	0.0712	0.0728	0.0630	0.0957
FR	0.1004	0.0787	0.1221	0.0949	0.0920	0.1000
GER	0.0411	0.0353	0.0549	0.1475	0.1190	0.1880
HU	0.0649	0.0545	0.0706	0.1664	0.1060	0.2489
ITA	0.0669	0.0487	0.0872	0.1447	0.1250	0.1967
NOR	0.1227	0.0833	0.1541	0.0533	0.0370	0.0780
POL	0.0447	0.0369	0.0526	0.1505	0.1200	0.1945
POR	0.0522	0.0225	0.0897	0.1982	0.1810	0.2204
SK	0.0385	0.0166	0.0530	0.1781	0.0680	0.2459
SP	0.4071	0.2114	0.6916	0.1453	0.1320	0.1780
SWE	0.0530	0.0376	0.0786	0.0678	0.0480	0.1024
UK	0.0914	0.0778	0.1148	0.1255	0.1060	0.1740
All	0.0892	0.0166	0.6916	0.1285	0.0370	0.2489

Finally, there is a group of countries switching from legal unbundling to ownership unbundling during our sample period (Czech Republic, Denmark, Italy, Norway, Poland, Portugal, Slovak Republic and Spain). Most countries introduced regulated third party access in the years 1999 or 2000, only Hungary (2002) and Germany (2006) came later (Sweden, Finland and the UK introduced regulated third party access already in 1995/96). With the exceptions of Belgium, Poland and the Slovak Republic, all countries either had already a liberalized wholesale market before the start of our sample period or introduced it during the sample period. Minimum consumption thresholds for freely choosing one's electricity supplier were either phased out during the sample period or were already abolished before 1998 in all countries. Rather diverse ownership structures can be observed across countries. While Germany, the UK and Belgium have either private or mostly private electricity sectors, the state still plays a major role in the other countries.

5. Econometric modeling

5.1. Error correction model (ECM) specification of investment

The most important determinant of investment should be the expected future profitability of investment. This would accompany the fundamental forward looking nature of investments: without capital market failures the firm should maximize its present value, given a set of capitalization rates of expected future returns and given a set of initial conditions (e.g. the existing stock of capital). If the firm maximizes the discounted flow of profits over an infinite horizon absent delivery lags, adjustment costs, and vintage effects, capital depreciates at a geometric rate and assuming a constant elasticity of substitution (CES) production function with σ the constant elasticity of substitution between capital and variable inputs, the relationship between the desired (optimal) capital stock K^*, the level of output Y, and the cost of capital c can be written as

$$K_t^* = \alpha c_t^{-\sigma} Y_t, \tag{1}$$

where c is a function of the purchase price of new capital relative to the price of output, see Chirinko (1993) and Caballero et al. (1995). Taking logs of Eq. (1) and denoting logarithms with lower case letters, we get

$$k_t^* = a - \sigma c_t + y_t. \tag{2}$$

In the absence of adjustment costs, k_t^* would be the optimal capital stock for a profit maximizing firm. Adjustment processes may be complex in the electricity industry, and one simple way to arrive at a tractable model and account for adjustment costs is to nest Eq. (2) within an autoregressive-distributed lag model, for example an autoregressive-distributed lag ADL (2,2) model of the form

$$k_t = \alpha_0 + \alpha_1 k_{t-1} + \alpha_2 k_{t-2} + \beta_0 y_t + \beta_1 y_{t-1} + \beta_2 y_{t-2} - \varphi_0 c_t - \varphi_1 c_{t-1} - \varphi_2 c_{t-2} + u_t. \tag{3}$$

If we simply take first differences, we get the corresponding error correction specification, similar to Bond et al. (2003):

$$\begin{aligned}\Delta k_t = {} & \alpha_0 + (\alpha_1 - 1)\Delta k_{t-1} + \beta_0 \Delta y_t + (\beta_0 + \beta_1)\Delta y_{t-1} \\ & - \varphi_0 c_t - \varphi_1 c_{t-1} - \varphi_2 c_{t-2} - (1 - \alpha_1 - \alpha_2) k_{t-2} \\ & + (\beta_0 + \beta_1 + \beta_2) y_{t-2} + \psi_t. \end{aligned} \tag{4}$$

Further including the real interest rate r, country-specific effects φ_i, incorporating additive year-specific effects η_t, assuming that electricity prices p (inversely) capture c (remember that the user cost of capital is a function of the purchase price of new capital relative to the price of output), and finally using the approximation that $\Delta k_t \approx I_{it} / K_{i,t-1} - \delta_i$,[15] we get the dynamic investment equation

$$\begin{aligned}\frac{I_{it}}{K_{i,t-1}} = {} & \alpha_0 + \alpha_1 \frac{I_{i,t-1}}{K_{i,t-2}} + \beta_1 p_{i,t-1} + \beta_2 p_{i,t-2} + \theta_0 \Delta y_{it} + \theta_1 \Delta y_{i,t-1} \\ & + \delta_2 k_{i,t-2} + \phi_2 y_{i,t-2} + \gamma_1 r_{i,t-1} + \gamma_2 r_{i,t-2} + \sum_{s=1}^{2} \mu_s REG_{i,t-s} \\ & + \sum_{s=1}^{2} v_s PO_{i,t-s} + \eta_t + \varphi_i + \psi_{it}, \end{aligned} \tag{5}$$

where we further add our variables measuring *regulation* (*REG*) and public *ownership* (*PO*). In the econometric estimation we exclude the prices of the actual period in order to reduce endogeneity problems. If adjustment costs to the desired capital stock are important in the electricity sector, we expect a positive and significant α_1. θ_0 and θ_1 measure accelerator effects, δ_2 and ϕ_2 error correction, i.e. a negative δ_2 or a positive ϕ_2 imply more error correcting future investments in case of the capital stock being below the long run relation given by Eq. (2). Positive β_1 and β_2 imply a trade-off between static and dynamic efficiency. The effects of regulation and ownership structure on investments are ambiguous, and depend on the trade-off between vertical synergies and competition, and the amount of X-inefficiency versus the objectives of the state, respectively. We measure γ by energy consumption.[16]

5.2. Empirical strategy

As has been pointed out previously, one has to deal carefully with inherent endogeneity and reverse causality problems of investment determinants. Namely, it could be that high investments in a country's electricity sector allow firms to set higher (regulated access) prices feeding into higher aggregate end consumer prices. It could also be that the regulatory variables are partly caused by high investments, e.g. the regulatory authority may be more confident to switch to ownership unbundling or stricter third party access if investments are high anyway. Causality would then also run from investments to our variables of interest. Accordingly, we start our empirical analysis by testing for (reciprocal) causality between investments and prices, and between investments and regulatory and ownership variables.

In testing for causality, we apply standard Granger (1969) causality tests. Namely, we use a standard joint test (i.e. χ^2-test) of exclusion

[15] The depreciation rate δ_i is subsumed into the unobserved country-fixed effects.
[16] Related investment models at firm level can be found in Cambini and Rondi (2010), who analyze the effects of incentive regulation on investment spending of the major European energy utilities and in Lyon and Mayo (2005) looking at the U.S. electric utility industry.

Table 2b
Regulatory variables and ownership.

Country	Ownership unbundling *OU*	Third party access *TPA*		Liberalized wholesale market *LWM*	Minimum consumption threshold *MCT*	Public ownership *PO*				
		Regulated	Negotiated		No threshold	Private	Mostly Private	Mixed	Mostly Public	Public
	Since	Since	Since	Since	Since	Since	Since	Since	Since	Since
AT	No	1999		2002	2001				1975	
BE	No	2000		No	2007		1975			
CZ	2005	2000		2000	2006				2004	1975
DK	2005	1999		1996	2002				1975	
FIN	1997	1995		1996	1997			1999	1975	
FR	No	2000		2002	2007				2006	1975
GER	No	2006	1990	2000	1998	1998		1975		
HU	No[a]	2002		2003	2007			1996		1975
ITA	2004	1999		2004	2007[b]			2005	2000	1975
NOR	2002	1991		1991	1991			2007	1975	
POL	2006	2000		No	2007				1999	1975
POR	2003	2000		2002	2002			1999	1989	1975
SK	2006	1999		No	2007				2004	1975
SP	2002	1999	1994	1999	2002		1997	1975		
SWE	1996	1996	1991	1996	1996					1975
UK	1995	1990		1990	1998	1995			1990	1975

TPA: Before regulated or negotiated *TPA* has been introduced in a country, there was always no TPA.
PO: The first year captured by OECD International Regulation Database is 1975.
[a] *OU* from 2004 until 2005 in Hungary.
[b] Between 2002 and 2003 no *MCT* in Italy, from 2004 until 2006 the threshold was 1 GW.

restrictions to determine whether lagged *X* has significant linear predictive power regarding current *Y*. The null hypothesis that *X* does not strictly Granger cause *Y* is rejected if the coefficients on the lagged variables of *X* are jointly/significantly different from zero. Bidirectional causality (or, feedback) exists if Granger causality runs in both directions. In particular, we consider two lags in order to test for Granger causality. Since we must include lagged dependent variables in these Granger tests, estimation with OLS would be inconsistent in the presence of unobserved country-fixed effects. Therefore, we estimate our equations with GMM. Granger causality tests are widely applied in this kind of analysis, see e.g. Cambini and Rondi (2012), Bortolotti et al. (2011), Gasmi and Recuero Virto (2010), and Edwards and Waverman (2006).

Based on the results of the Granger causality tests, we make use of instrumented regressions. Besides internal instruments in GMM we additionally incorporate external instruments. The country specific shares in hydro (*HYD*) and nuclear generation capacity (*NUC*) as well as the regulatory regime (*IR*) are used to instrument retail prices. The existence of incentive regulation of the power lines or higher shares in hydro or nuclear power generation capacity may directly correspond to lower final consumer prices, while investments may not be directly affected.[17] Furthermore, we deploy a set of variables that account for domestic institutions and country specific features to instrument the regulatory variables. Besides the degree of public ownership (*PO*), we rely on country-specific, time-varying measures from the applied political economy literature; namely, the political orientation of the executive in charge (*GOR*), the Herfindahl Government Index (*HERFGOV*) and the government stability (*STAB*).[18] Again, there are good reasons to believe that these indicators are directly linked to the regulatory variables, however, these variables may not directly affect the investment ratio.

Since our investment equation includes a lagged dependent variable, we cannot apply the standard instrumental variable estimation (2SLS) approach, due to the dynamic panel bias. In order to check the empirical relevance of our instruments, we perform a "quasi" first stage analysis, regressing prices (or the potentially endogenous regulatory variables) on the external variables in a simple OLS (or logit/ordered logit) framework. Finally, we end up with estimating instrumented GMM regressions.

6. Regression results

6.1. Granger causality tests

Table 3 presents our estimation results for the tests of strict Granger causality from *X* to *Y*. The table presents the *p*-values for the Granger-$\chi^2(2)$ tests. While prices significantly help predict investments in the subsequent two years, investments are also significant predictors for prices. Thus, we cannot exclude partial bi-directional causality between prices and investments. The same conclusions apply to *TPA*, *MCT* and *PO*, indicating that reverse causality is indeed an important issue in our case.

Table 3
Granger causality tests.

GMM	*p*-Value	Ho: $(\beta_1 + \beta_2 = 0)$	Answer
P causes *I*?	0.001	Rejected	Yes
I causes P?	0.038	Rejected	Yes
OU causes *I*?	0.003	Rejected	Yes
I causes *OU*?	0.410	Not rejected	No
TPA causes *I*?	0.678	Not rejected	No
I causes *TPA*?	0.039	Rejected	Yes
LWM causes *I*?	0.000	Rejected	Yes
I causes *LWM*?	0.577	Not rejected	No
MCT causes *I*?	0.396	Not rejected	No
I causes *MCT*?	0.054	Rejected	Yes
PO causes *I*?	0.002	Rejected	Yes
I causes *PO*?	0.005	Rejected	Yes

$(\beta_1 + \beta_2)$ denotes the joint coefficient of prices lagged once and twice, see Eq. (5); for the other variables the joint coefficients are estimated analogously.

[17] The introduction of incentive regulation should have a direct impact on final consumer prices, while a possible effect of incentive regulation on investment should be indirect via prices (which implies that the incentive regulation dummy is a valid instrument). In contrast, for the other regulatory variables we expect to have a direct effect on investment. The introduction of ownership unbundling potentially destroys vertical economies and thereby investment incentives, third party access as well as the establishment of a wholesale market describe the market entry conditions and therefore investment incentives, and finally, the severity of minimum consumption thresholds account for demand and/or accelerator effects.

[18] Thanks to an anonymous referee for this suggestion. This approach is quite common in the empirical analysis of applied political economy of regulation, see e.g. Bortolotti et al. (2013), Guerriero (2011), and Ai and Sappington (2002).

Table 4
Quasi first-stage-analysis results.

Dependent variable:	Log *P*	*OU*	*TPA*	*MCT*	*PO*
	OLS	logit	Ordered logit	Ordered logit	Ordered logit
NUC	−0.1365				
	(0.1772)				
HYD	−0.4996***				
	(0.1364)				
IR	−0.0410	2.6532***	3.7933***	1.1718***	−0.7765*
	(0.0727)	(0.5220)	(1.0785)	(0.4469)	(0.3966)
PO	−0.0608***	−0.1759	0.3342**	−0.4340***	
	(0.0175)	(0.1692)	(0.1704)	(0.1254)	
GOR	−0.0116	0.6287***	−0.0482	0.1875	0.0458
	(0.0277)	(0.2246)	(0.2490)	(0.1826)	(0.1671)
HERFGOV	0.4991***	−1.6640	−0.1324	−0.6972	−0.5097
	(0.1271)	(1.0920)	(1.1815)	(0.8626)	(0.5451)
STAB	0.1029	−0.7286	−0.3671	−0.3045	0.7092
	(0.0885)	(0.5485)	(0.7300)	(0.5904)	(0.4396)
Time dummies	Yes	Yes	Yes	Yes	Yes
F-test	6.68 (0.00)				
R-squared	0.3730				
Observations	188	200	196	200	200

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

In order deal with it, we run instrumented regressions, using both internal and external instruments.

The empirical relevance of our external instruments is indicated by the "quasi" first stage analysis (see Table 4), which shows that domestic institutions as well as country specific differences in the electricity generation mixes are significant determinants of final consumer prices (see first column). Thus, consumer prices are lower in those countries that have a higher share in nuclear or hydro power generation capacity, as these technologies have relatively low marginal costs. As one would expect, the introduction of incentive regulation leads to lower prices, however, the corresponding negative coefficient is not significant. A larger share of public ownership in the industry decreases prices, which is also true for a more left wing oriented government, though insignificantly. Moreover, the Herfindahl Government Index, controlling for the internal cohesion of the government, as well as government stability have positive signs.

Regarding the potentially endogenous regulatory measures *OU*, *TPA*, *MCT* and of public ownership, *PO*, Table 4 (columns 2–5) provides a consistent picture of the effects of the existence of incentive regulation. Incentive regulation increases the probability of further reforms, like ownership unbundling, regulated third-party access and lower thresholds for consumer switching. Moreover, it is negatively correlated to state-ownership. Interestingly, ownership unbundling is more likely in a country with a more left wing oriented government.

6.2. Main results

Tables 5a presents our main regression results, while Table 5b calculates short and long-run effects for the dynamic panel equations. The table compares country fixed effects estimates with GMM.[19] We perform regressions with and without error correction model (ECM) variables. The GMM model estimates the regression augmenting it by a lagged dependent variable as in Eq. (5) using the difference GMM estimator, thus consistently estimating a dynamic panel. This estimator eliminates country fixed effects by first-differencing and controls for possible endogeneity of current explanatory variables. Endogenous variables lagged two or more periods are valid instruments provided that there is no second-order autocorrelation in the first-differenced idiosyncratic error terms. Additionally, we make use of the external instruments as described before in order to see if our findings are still robust when using strictly exogenous information for our instruments, and we treat consumer prices as endogenous. The Sargan test does not reject the over-identifying restrictions at conventional levels. While there is evidence of first order serial correlation in the residuals, the AR(2) test statistics reveal absence of second order serial correlation in the first differenced errors. Our GMM estimates therefore could use variables lagged by two or more periods as instruments; however, due to the possible problem of too many instruments we restrict the maximum number of lags used as instruments to a maximum of three.[20] The Hausman test indicates that coefficient estimates via fixed effects are not significantly different from GMM estimates, thus the dynamic panel bias is not too important.

Four results stand out. First, lagged investment has a positive effect on investment activity in a country's electricity market in the current year. Therefore, investments in the electricity sector are characterized by path dependency, presumably because adjustment costs are large in high sunk cost industries. This is also underlined by the negative respectively positive error correction coefficients δ_2 and ϕ_2, implying gradual adjustment to the long run equilibrium relation (Eq. (2)). These results are consistent with the findings of Alesina et al. (2005) for seven regulated sectors in OECD countries.[21]

Second, we estimate a significant trade-off between static and dynamic efficiency. Table 5b indicates that the short and long-run effects of prices on investments with GMM without ECM are positive and significant, the fixed effects estimates are marginally significant.[22] In the long run, an increase in prices by 10% increases the investment ratio by 3–4%. This indicates that higher prices, while inducing static or allocative inefficiencies, increase the rents that can be earned from investments and trigger more investments, which increase dynamic efficiency. Note that all our regressions include country and year effects controlling for unobserved country (such as cost variations across countries) and business cycle effects. Thus, the time series variation in prices within countries most likely captures variations in the mark-ups over time, and thus rents to be earned from investments.

Third, ownership unbundling affects investment spending significantly negatively. Again looking at Table 5b, both short-run and long-run negative effects are sizeable and significant. Remembering the theoretical arguments from above, the most likely explanation is that non-internalization of spillover effects appear to outweigh any positive competitive effects. The second measure of direct *incumbent* regulation, third party access, also appears to reduce aggregate investment in the electricity sector, but less significantly so. In contrast, stricter direct *market* regulation appears to be beneficial to aggregate investment via spurring competition in the market, presumably because it does not reduce the incentives of the incumbent to invest. The presence of a liberalized wholesale market significantly increases investment spending in all estimations. Although the sign estimates point to the same conclusion, *MCT* effects are not significant. Our results imply that increasing competition via market-based instruments generally increase also aggregate investment (and not only competition). However, increasing competition via forcing the incumbent to provide cost-based access or via ownership unbundling mainly entails negative effects for aggregate investment.[23]

Finally, all estimates on public ownership lead us to conclude that it is detrimental to investments. The X-inefficiency following from public

[19] We also applied the LSDVC estimator by Bruno (2005), which is especially designed for dynamic unbalanced panel data models. Our main results remain unchanged and are available upon request.

[20] If we restrict the number of instruments even further, thereby reducing the number of instruments significantly, all results remain unchanged.

[21] Friederiszick et al. (2008), and Grajek and Röller (2009) find also large adjustment costs in the telecom sector.

[22] We do not obtain positive coefficients for prices if we include the error correction mechanism. Presumably, the intricate relations between prices, capital stocks and output are responsible for this.

[23] Note that this does not preclude positive static effects of these measures.

Table 5a
Determinants of investment.

Dependent variable: I_t/K_{t-1}	FE	GMM	GMM	GMM	GMM
	Without ECM	Without ECM	ECM	Without ECM	ECM
				With external instruments	With external instruments
	(1)	(2)	(3)	(4)	(5)
I_{t-1}/K_{t-2}		0.2841***	0.2351***	0.2731***	0.2314***
		(0.0628)	(0.0550)	(0.0621)	(0.0591)
Log P_{t-1}	0.1615	−0.0110	−0.1960*	−0.0434	−0.1363*
	(0.1057)	(0.0981)	(0.1097)	(0.0921)	(0.0739)
Log P_{t-2}	0.2114	0.3182**	0.1244	0.2620**	0.1053
	(0.1544)	(0.1259)	(0.0928)	(0.1255)	(0.0677)
OU_{t-1}	−0.0405	−0.0402	−0.0204	−0.0407	−0.0174
	(0.0465)	(0.0369)	(0.0302)	(0.0383)	(0.0292)
OU_{t-2}	−0.0684***	−0.0449**	−0.0396**	−0.0518***	−0.0361**
	(0.0152)	(0.0210)	(0.0201)	(0.0163)	(0.0184)
TPA_{t-1}	−0.0140	−0.0259	−0.0271*	−0.0307**	−0.0259**
	(0.0149)	(0.0162)	(0.0141)	(0.0150)	(0.0128)
TPA_{t-2}	−0.0196	−0.0109	−0.0160	−0.0116	−0.0179
	(0.0290)	(0.0182)	(0.0132)	(0.0174)	(0.0143)
LWM_{t-1}	0.0826*	0.0759***	0.0452**	0.0784**	0.0499**
	(0.0448)	(0.0292)	(0.0228)	(0.0324)	(0.0246)
LWM_{t-2}	−0.0157	−0.0023	0.0033	−0.0062	0.0023
	(0.0254)	(0.0155)	(0.0121)	(0.0172)	(0.0091)
MCT_{t-1}	0.0224*	0.0342**	0.0329**	0.0362**	0.0339**
	(0.0121)	(0.0166)	(0.0166)	(0.0170)	(0.0170)
MCT_{t-2}	−0.0134*	−0.0296***	−0.0253***	−0.0271**	−0.0251**
	(0.0071)	(0.0113)	(0.0097)	(0.0117)	(0.0105)
PO_{t-1}	−0.0362**	0.0074	0.0332	0.0033	0.0354
	(0.0150)	(0.0202)	(0.0233)	(0.0129)	(0.0235)
PO_{t-2}	−0.0558	−0.0957**	−0.0810**	−0.0974**	−0.0857**
	(0.0346)	(0.0431)	(0.0388)	(0.0436)	(0.0409)
Δ Log CON_t	0.0283	0.0561**	0.0552**	0.0583**	0.0589***
	(0.0175)	(0.0239)	(0.0216)	(0.0227)	(0.0223)
Δ Log CON_{t-1}	0.0530	−0.6581	−0.6372	−0.5373	−0.5974
	(0.4307)	(0.5294)	(0.4762)	(0.4967)	(0.4298)
Log r_{t-1}	0.1523	0.2405*	0.2404*	0.2329	0.2831*
	(0.1379)	(0.1338)	(0.1238)	(0.1480)	(0.1490)
Log r_{t-2}	0.0952	−0.0226	−0.0750	−0.0335	−0.1204
	(0.0632)	(0.0522)	(0.0560)	(0.0645)	(0.0802)
Log K_{t-2}			−0.1185***		−0.1054***
			(0.0173)		(0.0103)
Log C_{t-2}			0.2280		0.1007
			(0.1795)		(0.1606)
AR(1) p-value		0.0403	0.0455	0.0414	0.0432
AR(2) p-value		0.0881	0.0847	0.1921	0.0705
Sargan p-value		0.3039	0.5760	0.5965	0.8825
Time dummies	Yes	Yes	Yes	Yes	Yes
No. of instruments		63	65	70	72
Observations	87	75	75	72	72

Robust standard errors in parentheses.
In contrast to specifications (2) and (3), specifications (4) and (5) include the external instruments *NUC, HYD, IR, PO, GOR, HERFGOV*, and *STAB*. Hausman tests (Ho: difference in coefficients not systematic): FE no ECM vs. GMM no ECM: $p = 1$ (Ho cannot be rejected).
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

ownership and control appears to outweigh any positive objective effects due to state involvement on investments.

6.3. Robustness

6.3.1. More on reverse causality

Up until now we have already used the standard internal GMM as well as external instruments, and explicitly endogenized consumer prices in our regressions. In order to further use the information gained from the Granger causality tests, we now additionally treat those variables as endogenous in our GMM regressions, which show reciprocal causality in the underlying Granger causality tests, namely *MCT*, *TPA* and *PO*. Consequently, these variables are instrumented with GMM-type internal and external instruments, as it is the case for the lagged dependent variable.

Tables 6a (regression output) and 6b (short and long-term effects) report results on dynamic investment equations treating *prices and PO* as endogenous (column 1), and *prices*, *TPA*, *MCT* and *PO* as endogenous (column 2). We rely on the same external instruments as before. All our main results hold up, some become even clearer and more significant. Sargan tests as well as the tests for autocorrelation of order one and two are in line with our previous findings.

6.3.2. Different counterfactuals

One may criticize our approach in the foregoing sections by including all countries in the regression, i.e. also those countries that already had e.g. *OU before* the start of the estimation period. Thus, although we control for country effects, the control group may be somewhat contaminated, since the estimates of the effects of the introduction of *OU* are relative to a mixture of countries before the introduction of *OU*,

Table 5b
Short and long-term effects.

	FE	GMM	GMM ECM	GMM	GMM ECM
	(1)	(2)	(3)	(4)	(5)
Short log *P*	0.3728 ($p = 0.14$)	0.3072**	−0.0716	0.2186*	−0.0310
Long log *P*		0.4291**	−0.0936	0.3007*	−0.0403
Short *OU*	−0.1089*	−0.0851**	−0.0600**	−0.0924**	−0.0534***
Long *OU*		−0.1189***	−0.0784***	−0.1271***	−0.0695***
Short *TPA*	−0.0335	−0.0368	−0.0431*	−0.0422	−0.0437*
Long *TPA*		−0.0514	−0.0563*	−0.0581	−0.0569
Short *LWM*	0.0668*	0.0736**	0.0484*	0.0722**	0.0521*
Long *LWM*		0.1028***	0.0633**	0.0994***	0.0678**
Short *MCT*	0.0090	0.0046	0.0076	0.0090	0.0087
Long *MCT*		0.0064	0.0099	0.0124	0.0113
Short *PO*	−0.0920*	−0.0883**	−0.0478*	−0.0940***	−0.0503**
Long *PO*		−0.1233***	−0.0625**	−0.1293***	−0.0655***

Short-run coefficient $(\beta_1 + \beta_2)$ for prices; analogous for the other coefficients and variables.
Long-run coefficient $(\beta_1 + \beta_2) / (1 - \alpha_1)$ for prices; analogous for the other coefficients and variables.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

countries that never introduced *OU*, and countries that already had introduced *OU* before the start of the sample period. Therefore, we consider a subsample, including only those countries that switched from legal unbundling to ownership unbundling (CZ, DK, ITA, NOR, POL, POR, SK, SP) during our estimation period (1998–2008), as well as those countries that had not introduced *OU* by the end of the sample period (AT, BE, FR, GER, HU). Thus, the estimates of the effects of *OU* allow a before/after introduction of *OU* comparison relative to non-switching countries, i.e. a difference-in-difference comparison.

Table 7 presents the short and long-run effects of the main variables of interest. All our results hold up, and some are even more significant. Higher prices lead to higher investments in the specifications without ECM, and ownership unbundling and forced third party access decrease investment incentives, however, market based opening (*LWM* and *MCT*) increase investments. The effects of public ownership are again on the negative side.

Table 6a
Robustness: Endogeneity — regression results.

Dependent	GMM	GMM
Variable: I_t/K_{t-1}	*P* and *PO* end.	*P*, *TPA*, *MCT* and *PO* end.
	With external instruments	With external instruments
	(1)	(2)
I_{t-1}/K_{t-2}	0.2678***	0.2797***
	(0.0696)	(0.0625)
Log P_{t-1}	0.0079	−0.0444
	(0.0732)	(0.0807)
Log P_{t-2}	0.1917*	0.2576**
	(0.1014)	(0.1222)
OU_{t-1}	−0.0430	−0.0398
	(0.0404)	(0.0372)
OU_{t-2}	−0.0493***	−0.0524***
	(0.0170)	(0.0191)
TPA_{t-1}	−0.0285**	−0.0283**
	(0.0138)	(0.0135)
TPA_{t-2}	−0.0114	−0.0114
	(0.0168)	(0.0166)
LWM_{t-1}	0.0863**	0.0801**
	(0.0358)	(0.0325)
LWM_{t-2}	−0.0055	−0.0050
	(0.0188)	(0.0159)
MCT_{t-1}	0.0356**	0.0361**
	(0.0157)	(0.0165)
MCT_{t-2}	−0.0308**	−0.0292**
	(0.0128)	(0.0117)
PO_{t-1}	0.0089	0.0053
	(0.0149)	(0.0139)
PO_{t-2}	−0.1150**	−0.0968**
	(0.0467)	(0.0426)
Δ Log CON_t	0.0460**	0.0605**
	(0.0192)	(0.0242)
Δ Log CON_{t-1}	−0.4483	−0.5350
	(0.4532)	(0.4848)
Log r_{t-1}	0.2616*	0.2349
	(0.1565)	(0.1505)
Log r_{t-2}	−0.0591	−0.0384
	(0.0789)	(0.0694)
AR(1) *p*-value	0.0371	0.0406
AR(2) *p*-value	0.0979	0.0981
Sargan *p*-value	0.5230	0.6474
Time dummies	Yes	Yes
No. of instruments	68	71
Observations	72	72

Short-run coefficient $(\beta_1 + \beta_2)$ for prices; analogous for the other coefficients and variables. Long-run coefficient $(\beta_1 + \beta_2) / (1 - \alpha_1)$ for prices; analogous for the other coefficients and variables.
Specifications (1) and (2) also include the external instruments *NUC*, *HYD*, *IR*, *PO*, *GOR*, *HERFGOV*, *STAB*.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

7. Conclusions

Estimating dynamic panel regression models for 16 European countries over the period 1998–2008, we test for the interrelations between investments, prices and regulation in a regulated network industry, the electricity industry. We find evidence for the presence of both kinds of trade-offs, the trade-off between static and dynamic efficiency, and the trade-off between vertical synergies and competition.

We come to a rather negative conclusion concerning the dynamic effects of ownership unbundling of the transmission grid. Unbundling of ownership of the generation from the grid stages reduces the aggregate investment rate in the sector by about 10%. We also estimate an investment reducing effect of forced third party access to the transmission grid. Higher electricity end-user prices induce higher investments in the overall sector.

However, we do not argue that competition introduced via regulation per se reduces investments, instead that the *way* competition is introduced has important consequences. Giving entrants direct access to the incumbent's network via cost based access charges or ownership unbundling the incumbent's grid from other stages of the supply chain, introduces vertical diseconomies and non-internalization of network effects and spillovers, such that the net effect on aggregate investment is negative, at least in electricity markets. Introducing competition via *market* based measures – such as establishing a wholesale market for electricity or abolishing minimum consumption thresholds for switching to alternative suppliers – increases aggregate investment spending. These measures increase competition and investment spending *without* destroying the incentives of the incumbent to invest.

We looked – for data reasons – at aggregate investment in the electricity sector, which we believe is important for total welfare. However, we caution that we are constrained to analyze only the net effects of regulation on aggregate investment, future work should look at the effects of regulation on the different stages in electricity (generation, transmission, distribution) and on the differential effects on incumbents versus entrants.

Theory indicates that there are inherent trade-offs in high sunk cost network industries. There is a trade-off between static and dynamic efficiency, and there is a trade-off between vertical synergies and competition. Higher prices induce static inefficiencies, but they induce firms

Table 6b
Robustness: Endogeneity — short and long-term effects.

	GMM	GMM
	P and *PO* end.	*P*, *TPA*, *MCT* and *PO* end.
	With external instruments	With external instruments
	(1)	(2)
Short log *P*	0.1995 (p = 0.11)	0.2132*
Long log *P*	0.2724 (p = 0.11)	0.2960*
Short *OU*	−0.0922**	−0.0922**
Long *OU*	−0.1260***	−0.1280***
Short *TPA*	−0.0399	−0.0397
Long *TPA*	−0.0545	−0.0551
Short *LWM*	0.0807**	0.0750**
Long *LWM*	0.1103***	0.1042***
Short *MCT*	0.0048	0.0069
Long *MCT*	0.0065	0.0096
Short *PO*	−0.1060***	−0.0914***
Long *PO*	−0.1448***	−0.1269***

Short-run coefficient $(\beta_1 + \beta_2)$ for prices; analogous for the other coefficients and variables. Long-run coefficient $(\beta_1 + \beta_2) / (1 - \alpha_1)$ for prices; analogous for the other coefficients and variables.
Specifications (1) and (2) also include the external instruments *NUC*, *HYD*, *IR*, *PO*, *GOR*, *HERFGOV*, *STAB*.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

to invest, ownership unbundling prohibits discrimination among firms and ameliorates allocative efficiency, but it decreases incentives to invest. Not surprisingly, we find that there is no free lunch in economics.

Table 7
Robustness: switching countries and never switched countries.

	FE	GMM	GMM ECM	GMM	GMM ECM
				With external instruments	With external instruments
	(1)	(2)	(3)	(4)	(5)
Short log *P*	0.3824	0.2243*	−0.0373	0.2439*	−0.0091
Long log *P*		0.3076*	−0.0474	0.3482*	−0.0121
Short *OU*	−0.0983*	−0.0888***	−0.0436**	−0.0769**	−0.0448**
Long *OU*		−0.1218***	−0.0554**	−0.1098**	−0.0592**
Short *TPA*	−0.0329	−0.0243	−0.0406	−0.0381	−0.0431*
Long *TPA*		−0.0333	−0.0516	−0.0544	−0.0570
Short *LWM*	0.0751*	0.0946***	0.0632***	0.0861**	0.0534**
Long *LWM*		0.1297***	0.0802***	0.1229***	0.0706**
Short *MCT*	0.0188*	0.0087	0.0120	0.0080	0.0085
Long *MCT*		0.0120	0.0152	0.0114	0.0113
Short *PO*	−0.0771*	−0.0967***	−0.0582**	−0.0934***	−0.0597***
Long *PO*		−0.1326***	−0.0738***	−0.1333***	−0.0788***
AR(1) *p*-value		0.0527	0.0605	0.0573	0.0647
AR(2) *p*-value		0.8509	0.5723	0.8282	0.6195
Sargan *p*-value		0.2438	0.4534	0.3211	0.5917
Time dummies	Yes	Yes	Yes	Yes	Yes
No. of instruments		54	56	53	55
Observations	73	63	63	60	60

Short-run coefficient $(\beta_1 + \beta_2)$ for prices; analogous for the other coefficients and variables. Long-run coefficient $(\beta_1 + \beta_2) / (1 - \alpha_1)$ for prices; analogous for the other coefficients and variables.
In contrast to specifications (2) and (3), specifications (4) and (5) include the external instruments *NUC*, *HYD*, *IR*, *PO*, *GOR*, *HERFGOV*, *STAB*.
* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.01$.

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